Evaluation of Allometric Equations for Estimating Above-ground Tree Biomass and Stand-Level C Accumulation

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INTRODUCTION

A recent report by the British Royal Society concluded that current approaches are insufficient to accurately measure and account for interannual changes in terrestrial carbon budgets (The Royal Society 2001). Estimates of tree and/or stand biomass and carbon content on the Walker Branch Watershed have been determined for many years from allometric data generated as a part of the International Biological Program (Harris et al., 1973).

Allometry is defined as the measure and study of growth or size of a part in relation to an entire organism (Parresol, 1999). Allometric equations that relate tree diameter at breast height (1.3 m) to other attributes such as standing carbon stock and leaf area are an important and often-used tool in ecological research as well as for commercial purposes (Martin et al., 1998). Such tools represent the primary method for estimating above-ground forest dry matter or carbon stocks (Brown et al. 1999).

Previously developed allometric equations are applied to forest systems of interest under the assumption that the populations being studied are very similar to those for which the relationships were calculated. This assumption must be tested vigorously however, as small errors can multiply significantly as the scale of estimation increases. Martin et al. (1998) found considerable differences (up to 40%) between biomass estimates derived from localized allometric relationships and regional ones developed by Clark and Schroeder (1986). Such concerns have caused us to ask a series of questions regarding efficacy of biomass allocation data for Walker Branch Watershed, including:

How stable are allometric relationships over time?

How variable are estimates of stand biomass derived from published allometric relationships?

How important are the use of species-specific allometric relationships for estimates of stand biomass?

METHODS

Trees with diameters ranging from 22 to 66 cm were identified on Walker Branch for comparison to historical allometric data for species common to eastern upland oak forests. Selected trees were harvested and separated into leaves, branches and bole components and wet mass of each was measured with a large capacity digital balance to the nearest 0.1 Kg (Figure 1). Subsamples of each tissue type were collected and oven dried to constant mass to determine the water content of the fresh tissue. Wet mass data were converted to dry mass with the corresponding conversion factors.

A data set for the relationship between dbh and tree mass was formed from the combination of new measurements and existing observations compiled from similar sites within the region (Solllins and Anderson 1971). An exponential fit to this data set yielded a 'revised' allometric relationship for application to the upland oak forest type of Walker Branch Watershed (Figure 2). Similar species-specific relationships were also developed from the new data set.

Above-ground stand biomass (branches and boles) for a typical upland oak forest (Hanson et al. 2001) was estimated using four generalized hardwood allometric relationships applied to all species (See equations in Table 1). In addition, species-specific allometric data for our site and from published sources (Martin et al. 1998, Ter-Mikaelian and Korzukhin 1997) were used to estimate mass of corresponding species and integrated to the stand total.

Stand biomass was converted to carbon equivalents assuming 0.47 gC g dry matter^{-1}.

Figure 1. The harvest process. Small trees could be harvested in 1 to 2 days, however, an individual chestnut oak (*Quercus prinus L.*) tree with a diameter of 66 cm required 30 person days.

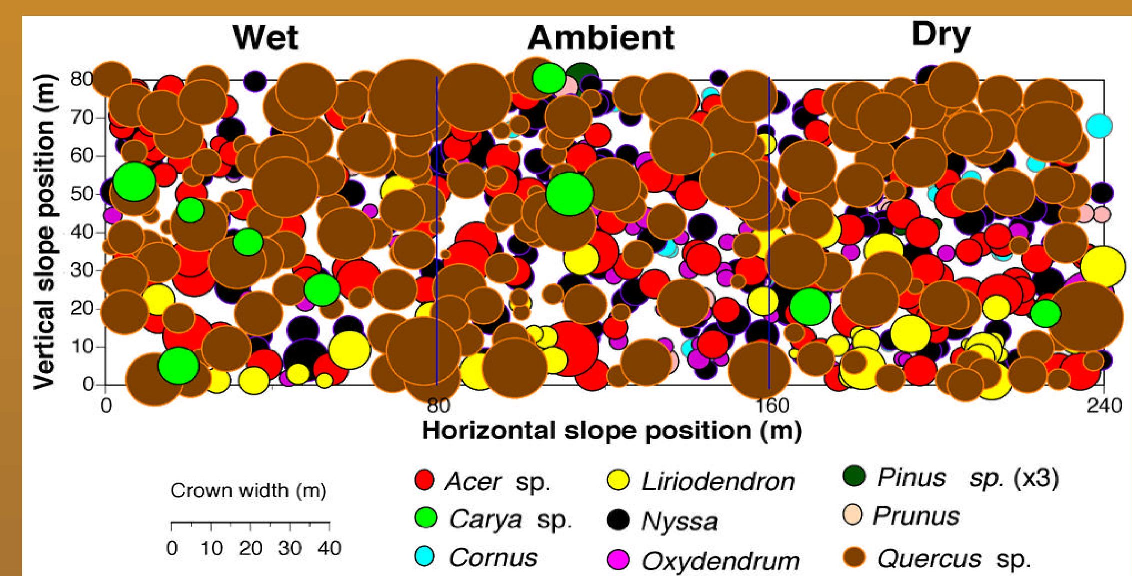

Figure 2. Species composition of representative site on Walker Branch Watershed. *Acer*=Maple; *Carya*=Hickory; *Cornus*=Dogwood; *Liriodendron*=Poplar; *Nyssa*=Blackgum; *Oxydendrum*=Sourwood; *Pinus*=Pine; *Prunus*=Black Cherry; *Quercus*=Oak

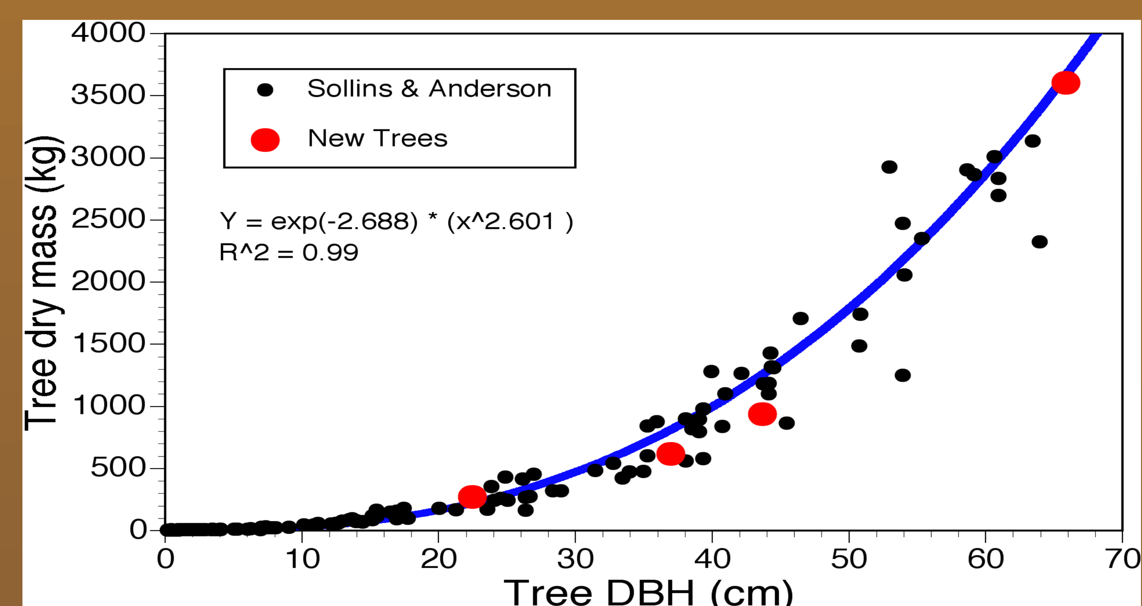

Figure 3. Four trees from Walker Branch harvested in 2001 plotted against regional data published by Sollins and Anderson for trees harvested prior to1971. Resulting allometric equation was used to estimate stand biomass and C accumulation for Walker Branch site.

RESULTS

Data for four new trees agreed well with previously published data for eastern hardwood forests (Figure 3).

The use of alternative generalized allometric equations produced notable differences in estimates of tree mass at stem dbh greater than 50 cm (Figure 4).

Alternative allometric relationships yielded estimates of mean annual stand C accumulation ranging from 228 to 360 gC m^{-2} y^{-1} (Figure 5) for the 1993-2000 period. The estimate based on our newly revised allometric relationship for Walker Branch Watershed is 22% greater than for the previously used relationship published by Harris et al. (1973).

In all cases, the estimates of C accumulation which were derived from species-specific allometric equations were larger than those from equations generalized for all species (Figure 5).

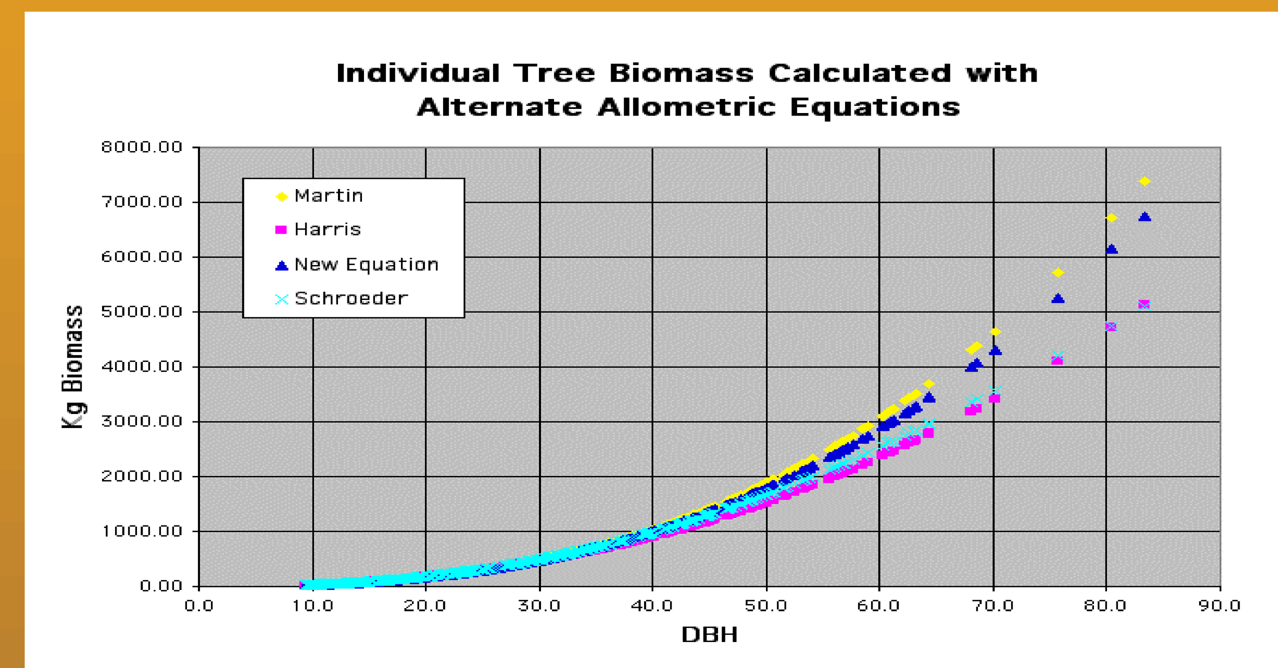

Figure 4. Generalized allometric relationships for multiple species located on Walker Branch site.

CONCLUSIONS

Estimates of above ground biomass or carbon stocks and their change with time are highly dependent on the source of allometric data. Brown et al. (1999) noted that allometric studies often rely upon samples that are too small and not selected "in a statistically valid manner from the population of interest." Additionally, Schroeder et al. (1997) pointed out that the DBH range for many samples is too limited to provide appropriate relationships for mature forests. Other potential errors in estimation may result from differences in biomass allocation or morphology from one forest system to the next. Species composition within a system can also play an important role, as differences in wood specific gravity and height (among other characteristics) can vary considerably between species (Martin et al., 1998).

Allometric estimates based on the integration of species-specific data produced higher estimates of standing C stocks and annual C increments.

Allometric methods for estimating above-ground biomass and C stocks at Walker Branch produced acceptable estimates for annual C accumulation in branches and wood of 279±12 gC m^{-2} y^{-1}. The variability around this mean due to the source of allometric data (4.3%) is very similar to spatial sampling error associated with litter production estimates (2%).

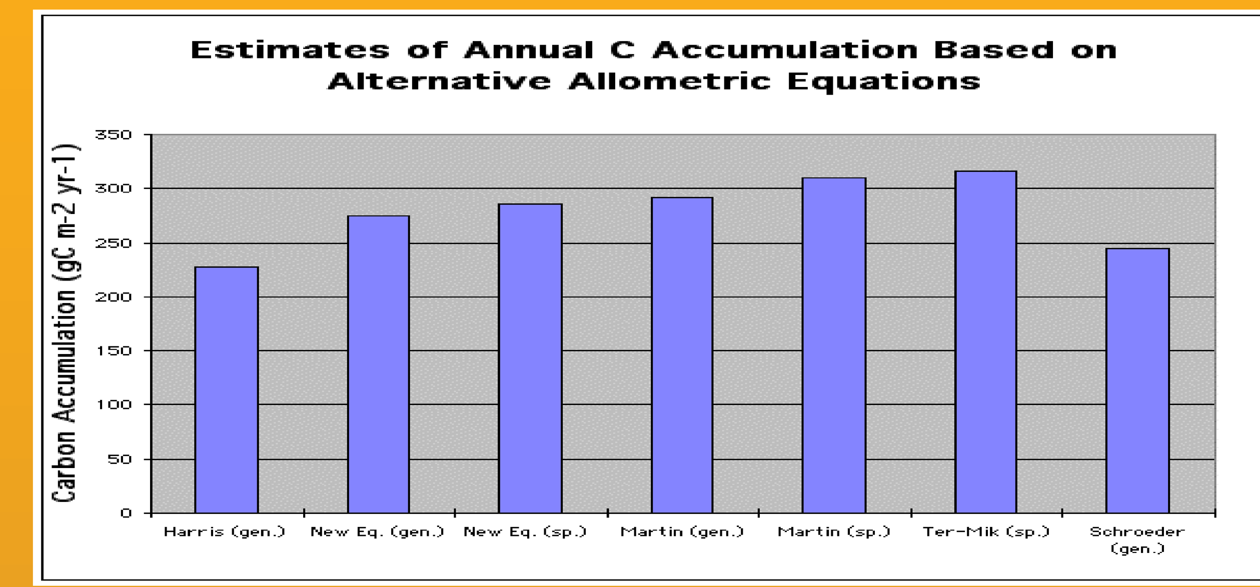

Figure 5. Comparing estimated C accumulation from several differing allometric relationships. "Gen."=generalized equations; "Sp."=species-specific equations. For further explanation of individual equations, see Table 1.

Table 1. Equations used to estimate aboveground stand biomass. "General"=equations generalized for all species; "Specific"=equations specific to individual species. Y=biomass in kg; X=diameter at breast height; "a" and "b" vary depending upon the species.

Label	Equation/Form	Type	R^2	Ref.
Martin(generic)	Y=10^(-1.28+log10X*2.68)	General	.99	Martin et al. 1998
Martin(species)	Y=10^(a+log10X*b)	Specific	.98-.99	Martin et al. 1998
Harris (bole)	Y_{bole} = Exp(-2.44+LN(X)*2.42)*1.08	General	.97	Harris et al. 1973
Harris (branch)	Y_{branch} = Exp(-3.189+LN(X)*2.23)*1.26	General	.91	Harris et al. 1973
Harris (total)	$Y_{total} = Y_{bole} + Y_{branch}$	General	N/A	Harris et al. 1973
New (generic)	Y=Exp(-2.69)*(X^2.60)	General	.99	N/A
New (species)	Y=Exp(a)*(X^b)	Specific	.98-.99	N/A
Ter-Mik	Y=aX^b	Specific	≥.95	Ter-Mikaelian. 1997
Schroeder	Y=0.5+(25,000X^2.5/ X^2.5+246,872)	General	.99	Schroeder et al. 1997

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